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OPTIMIZATION OF RECUPERATER FIN GEOMETRY FOR MICRO GAS TURBINE

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ABSTARCT: Recuperater is used in micro gas turbine to recover the waste heat from the turbine exhaust and boost the thermal efficiency of the gas turbine. Effectiveness of the recuperater depends on the many factors; one among these is surface area for heat transfer per unit volume. This paper describes various fin geometries considered for improving the effectiveness of the recuperater used in Micro Gas Turbine. Through CFD analysis it was shown that inclined corrugated fins having 45 deg. inclination has higher effectiveness compared to conventional flat or straight corrugated fins. The flow within the corrugated channels was studied in detail to understand flow physics.

1. INTRODUCTION

Micro Gas-turbines (MGT) is used for stationary power generation. MGT offer many advantages namely ability to provide reliable backup power, less maintenance and longer lifetime. They are compact in size, lighter weight, greater efficiency, lower emissions, and quicker starting. Micro Gas-turbine unit is comprised of a compressor, combustor, turbine, recuperater, and an alternator. The compressed air is mixed with fuel and burned under constant pressure condition in combustor. The hot gas is allowed to expand through a turbine to perform work. Recuperated unit in MGT use a heat exchanger that recovers some of the heat from turbine exhaust and transfers it to the incoming air stream from compressor for combustion. By using recuperaters micro gas turbine can reach 25 to 30 percent thermal efficiency.

2. BACKGROUND

Holger Martin [1] describes plate and frame heat exchangers with chevron (or herringbone) corrugation patterns. Utriainen and Sunde´n [2] reviewed the chevron pattern heat transfer surface to assess the thermal and hydraulic performance and concluded that the Cross Corrugated surface has great potential for use in recuperaters. Gradeck [3] used the local temperature measurements to evaluate the local and global heat transfer coefficient of the wavy heat exchanger. Sang Dong Hwang [4] investigated the flow and heat/mass transfer characteristics of wavy duct for the primary surface heat exchanger application. The flow visualization technique and a numerical analysis using a commercial code, FLUENT, are used to understand the overall flow structures inside the duct. Kenichi MORIMOTO [5] studied detailed mechanism of heat transfer enhancement on the oblique wavy wall for recuperaters and obtained optimal shape design of the passage geometry. Gunnar Lagerström [6] developed laser-welded recuperater for micro gas turbine application. Tests have shown that thermal performance is very competitive.

3. OBJECTIVE

The micro gas turbine annular recuperater with plate fins was designed and fabricated for a MGT at Propulsion Division, National Aerospace Laboratories, Bangalore. The experimental studies of this unit (Figure-1) proved the effectiveness value of recuperater achieved is very small and its effect on micro

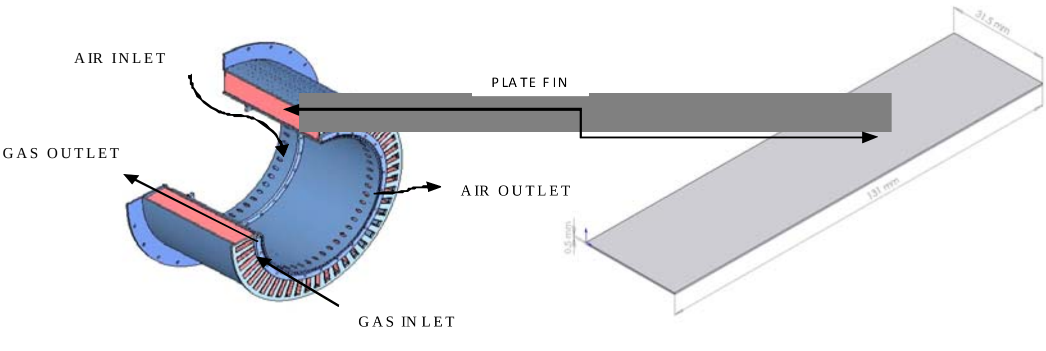

Figure-1 Flat fin recuperater for MGT

gas turbine performance is significant. Alternative fin designs have been evolved to get an enhanced heat transfer surface area to improve effectiveness value with minimum pressure loss. Single corrugated and double corrugated (Chevron) fin geometry were considered and optimized by varying corrugation angle. The basic profile for the fin is generated using analytic function. The height and pitch (amplitude and wave length) ratio for the profile was fixed at an optimum value.

4. MODELLING AND ANALYSIS

The fin geometry was modeled using SOLIDWORKS and saved in Para-solid for importing to commercial CFD pre-processor GAMBIT for meshing. Due to axi-symmetric shape of the recuperater only sector model having one air passage and half gas passage on either side of air passage is modeled. The models generated for two fin geometries are shown in Figure-2. Gas passage and fins are map

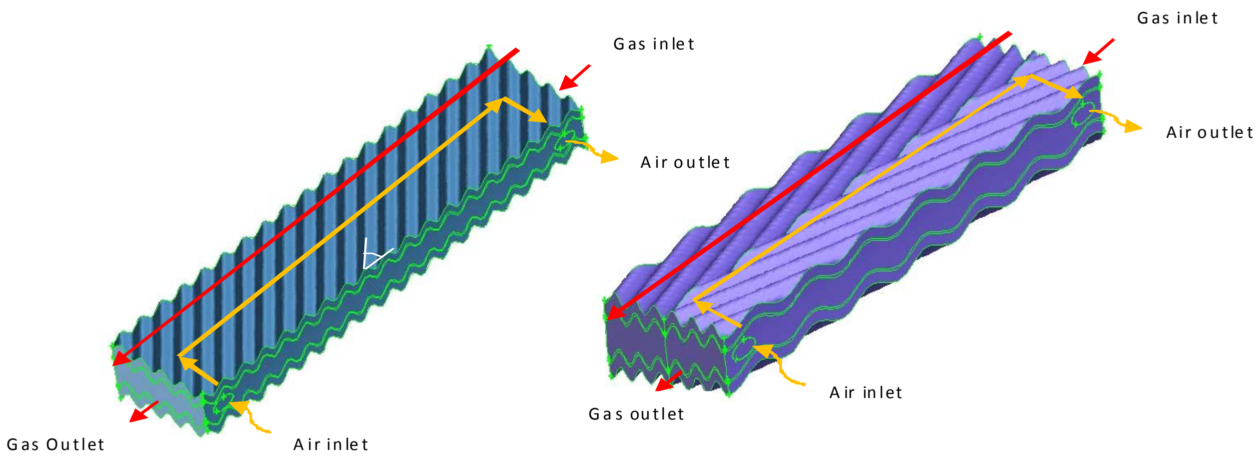

Figure-2 Single and Double Corrugated Fin Models

meshed using hexahedral element. While meshing the fins care has been taken to generate more than four elements in the direction of fin thickness. Air passage is auto meshed using tetrahedral elements as it was difficult to mesh this passage with hexahedral map mesh. Analysis were performed with different computational grid sizes to get a dependable results. Figure-3 shows the comparision of the results for straight corrugated model with different grid size with respect to effectiveness value of heat exchanger. It is observed that after certain value of grid size the computed effectiveness is found to be independent of grid. Based on this analysis a grid size of 6 to 7 lakhs was found to be sufficient to get dependable results from the analysis. It is assumed that this grid size will give dependable results for rest of configurations.

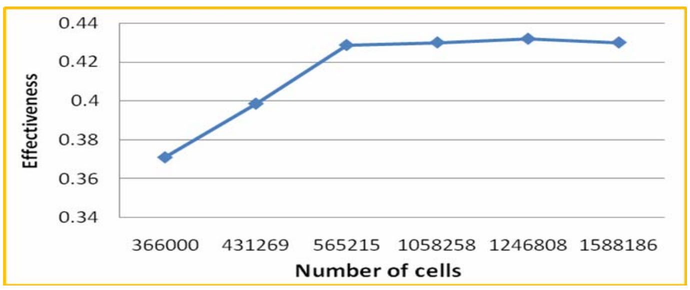

Figure-3Grid independency study

Spalart-Allmaras single equation turbulence model is used in the analysis. Total Pressure at inlet and static pressure at outlet were specified as boundary conditions. Periodic boundary condition is used due to symmetrical shape of annular recuperater. Commercial CFD solver namely FLUENT was used to solve the mass, momentum and energy equations. Fluid properties are defined for air and gas medium and appropriate material properties for fin. Functions are defined to calculate the performance namely effectiveness and pressure loss values for the recuperater. The residual of velocity components along with effectiveness, air outlet temperature, and gas outlet tempreture are monitored for each iteration. Various criteria like minimum residual (< $1x10^{-6}$), insignificant change in velocity profiles and overall mass balance were used to decide appropriate level of convergence.

5. RESULTS

Experimental validations of CFD results are very important as far as reliability and accuracy are concerned. Some of the experimental results available on plain and straight corrugated fin geometries were theoretically analysed. One typical results for design point operation of the recuperater is shown in TABLE-I. The estimated values of effectiveness are close to the experimental results.

TABLE-I Comparison of Effectiveness values

Configuration	**CFD**	**Experiment**
Flat plate fin	32.47	30.85
Straight corrugated fin	40.22	38.59

Figure-3 shows the performance of single corrugated fin geometry. It is observed that the optimum corrugation angle is 45 degrees for maximum effectiveness. The pressure loss increases with increase in corrugation angle. This is mainly due to flow reversal in flow passages at higher corrugation angle. The maximum effectiveness that could be achieved in single corrugated fin is about 53%. It is observed from experimental studies, single corrugated fin has higher effectiveness as compared to straight fin. This is mainly due to higher surface area and higher heat transfer due to mixing. The effectiveness and total relative pressure loss variation

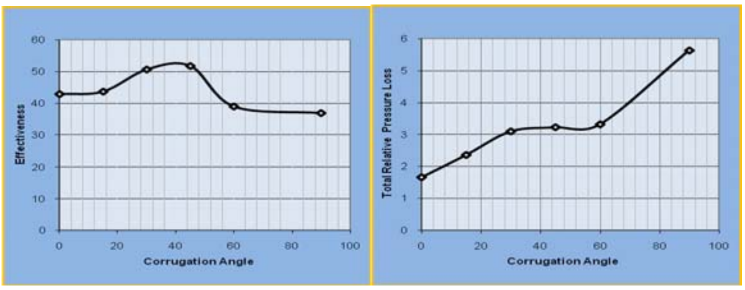

Figure-3 Performance of Single Corrugated Fin

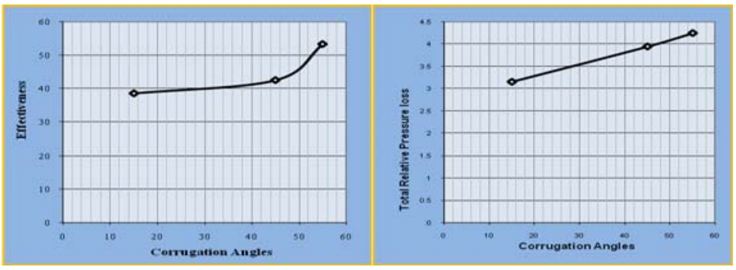

Figure-4 Performance of Double Corrugated Fin

with corrugation angle for double corrugated fin is shown in Figure-4. It is observed from this figure, the effectiveness and total relative pressure loss increases with corrugation angle. No optimum point was found within the range of corrugated angles considered. The effectiveness achieved for a given corrugation angle is lower than the single corrugated fin. The comparison of effectiveness with single and double corrugated fin indicate the single corrugated fin has higher effectiveness up to 50degree corrugation angle. For corrugation angles more than 50 degree the effectiveness of double corrugated fin is higher than single corrugated fin. The relative total pressure loss for double corrugated fin is always higher than the single corrugated fin at all angles. This is due to large flow disturbance and mixing at the intersection of the two corrugations.

Figure-5 shows, velocity vectors colored by velocity magnitude in middle of the air passage. This plot gives a picture about how the air particles will travel inside the air flow passage. It is observed that flat fin provides a large recirculation region. This recirculation region extends up to the exit. The recirculation region reduces as the fin geometry is being changed from flat to straight corrugation, and cross corrugation. The smallest recirculation region exists for cross corrugation fin geometry, which has greatest mixing of flow.

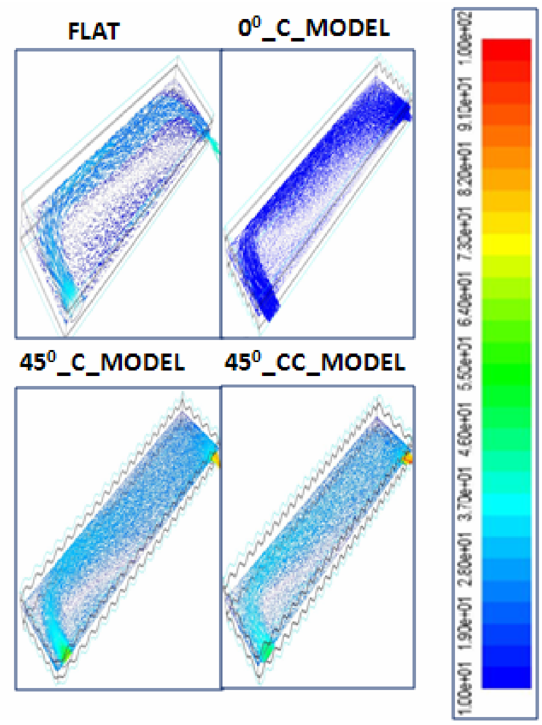

Figure-5 Velocity vectors in the center of air passage

Figure-2 gives contours of total temperature variation along the gas and air paths for all four kind of fins model. It is observed that for flat plat fin and straight corrugated fin models the convective heat transfer from fin surface to air is not taking place uniformly, due to lack of fully developed flow. The higher temperature zones are observed where reversed flow is taking place because recirculation of heated air increases the air temperature. It is observed that large heat transfer exists between cold air and hot gas in cross corrugated fin geometry.

6. CONCLUSIONS

CFD analysis of single corrugated fin geometries and double corrugated fin geometries have provided good understanding of the fluid flow and heat transfer phenomenon in the flow passages of the recuperater. The inclined corrugated fin provides greatest effectiveness without penalty on pressure loss. As compared to flat and straight corrugated fin geometries. The optimum inclination angle was found to be 45 deg. The double corrugation fin geometry shows increase in effectiveness with increase in corrugation angle.

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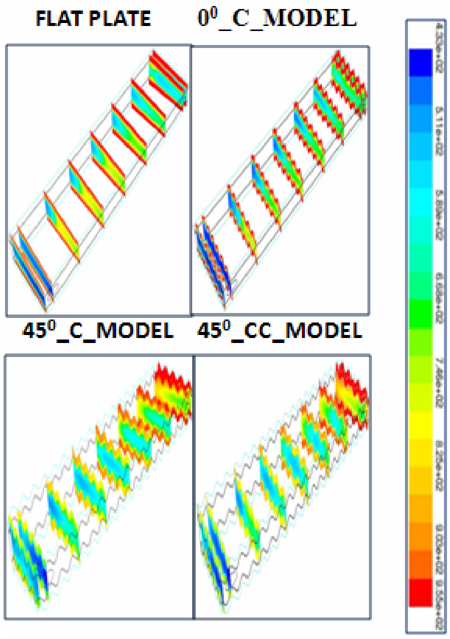

Figure-6 Temperature variation along gas and air passages

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